Optimizing Liner Shipping Network considering Empty Container Repositioning

Heng Wang †
Department of Systems Innovation
The University of Tokyo, Tokyo, Japan
Tel: (+81) 3-5841-6009, Email: k.oh.920718@gmail.com

Kenji Tanaka
Department of Systems Innovation
The University of Tokyo, Tokyo, Japan
Tel: (+81) 3-5841-6009, Email: kenji_tanaka@sys.t.u-tokyo.ac.jp

Abstract. This paper proposes a planning system for empty container repositioning. It is said that movement of empty containers account for thirty percentage of movement of all containers. This is because the amount of trade by marine logistics is different between countries. Empty container repositioning cost no less than 234 million dollars in 2010. Therefore, we have developed planning system to reduce the cost of repositioning empty containers. To achieve this purpose, we have developed a planning system for empty container repositioning. This system includes demand prediction, inventory control, and determination of transportation plan. We optimize the stock of empty containers at each port by demand prediction and inventory management, and we optimize the whole network of empty container repositioning by determining transportation plan. We have developed simulator including these three methods, and carry out the simulation. Then, we applied this system to marine logistics network. We compared current scenario and our system scenario. The result of these simulations suggests that the cost of empty container repositioning can be reduced by our planning system, and empty container repositioning is achieved by our planning system.

Keywords: empty container repositioning, marine logistics, optimization, demand prediction, recurrent neural network

1. INTRODUCTION

The number of movement of the containers has been increased constantly in recent year. It was 29 million TEUs in 1990, however it was even increased 186 million TEUs in 2014. One reason of this increase is that European and American manufacturers concentrate factories on Asia, and export produced product from Asia to Europe or America. Because of this trend, the imbalance of trade by marine logistics has been occurred. Figure 1 shows the number of movement of the containers among Asia, Europe, and America in 2013. According to Figure 1, the number of containers from Asia to Europe and America is about twice as many as the number of containers from Europe and America to Asia. Therefore, there is short of empty containers in Asia, and there is surplus of empty containers in Europe and America. Because of this imbalance of empty containers, empty container repositioning is required.

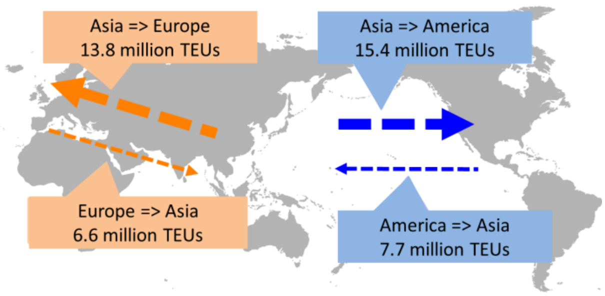

Figure 1: Movement of the containers in the world

It is said that movement of empty containers account for thirty percentage of movement of all containers. However, empty container repositioning earns no profit for shipping companies. On the other hand, Empty container repositioning makes a great cost for shipping companies.

According to the research company, empty containers repositioning cost no less than 234 million dollars in 2010. Therefore, we have developed planning system to reduce the cost of repositioning empty containers.

2. LITERATURE REVIEW

There are some studies about inventory control of empty containers. Li et al. (2004) considered the problem to be a nonstandard inventory problem with positive and negative demands at the same time under a general holding-penalty cost function and one-time period delay availability for full containers just arriving at the port. Song and Zhang (2010) focused on optimal policy for empty container repositions at a single port. Yin et al. (2012) formulated a two-stage stochastic programming model with random demand, supply, ship weight capacity, and ship space capacity. However, these studies only considered the inventory control of empty containers at single port. The exchange of empty containers among multiple ports should be considered to achieve empty container repositioning.

There are other studies about the exchange of empty containers among multiple ports. Meng and Wang (2011) proposed a liner shipping service network design problem with combined hub-and-spoke and multi-port-calling operations and empty container repositioning. Zheng et al. (2015) focused on an empty container allocation problem considering the coordination among liner carriers to reduce the empty container repositioning costs. Akyuz and Lee (2016) considered the optimization of speed of ships to determine the best route for transporting empty containers. However, these studies only considered the exchange of empty containers among multiple ports. The inventory control of empty containers should be considered to reduce the cost of repositioning empty containers.

Therefore, this paper considers both of the inventory control and the exchange of empty containers among multiple ports. Moreover, this paper also considers the demand prediction of empty containers.

In addition, previous papers only considered transportation of empty containers. However, these papers did not consider transportation of full containers. The transportation of full containers should also be considered to use port effectively.

Therefore, this paper considers both of empty and full containers.

3. MODEL

3.1 Outline of model

We have developed a planning system to reduce the cost of repositioning empty containers. Figure 2 shows the procedures of this model.

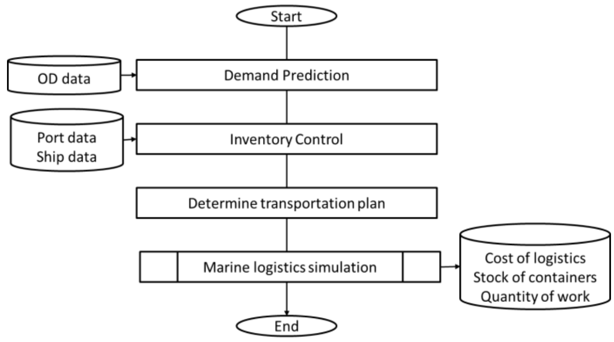

Figure 2: Procedures of the model

First, we predict the demand of empty containers at each port. We use the previous demand data to predict future demand by machine learning.

Next, we consider inventory control of empty containers. We determine the minimum stock of empty containers at each port enough to cover the demand of empty containers.

Then, we determine the transportation plan. We define the total cost of empty container repositioning as the sum of the storage cost, the lease cost, the handle cost, and the fuel cost. We determine the number of handled empty containers and leased empty containers at each port to minimize the total cost.

Finally, we carry out marine logistics simulation to optimize empty container repositioning. With the result of this simulation, we can evaluate the cost of marine logistics, the stock of empty containers at each port, and the quantity of work to load and unload containers at each port.

3.2 Demand prediction

In order to reduce the cost of empty container repositioning, we consider prediction of demand of empty containers at each port. The storage cost and the lease cost can be reduced by appropriate demand prediction. We use the previous demand data to predict future demand by Recurrent Neural Network (RNN).

RNN is a class of the neural network methods. Conventional neural network do not consider time series data. RNN expand neural network to be able to handle time series data. Figure 3 shows the concept of RNN.

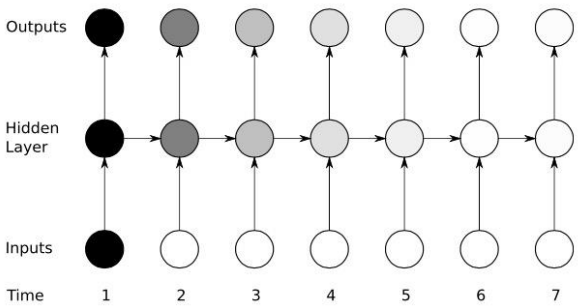

Figure 3: The concept of RNN

We predict the demand of empty containers at each port by RNN every day. By adding prediction of each day at each port, we calculate the prediction of accumulated demand of empty containers. We define P_{dp} as the prediction of accumulated demand of empty containers at port p during d days.

3.3 Inventory control

We consider shortage rate and safety factor of the stock of empty containers in order not to be short of empty containers at each port. Shortage rate means the probability of occurrence of shortage. Safety factor is decided by the allowance of shortage rate. The bigger the allowance of shortage rate is, the smaller safety factor is. Table 1 shows the relation between shortage rate and safety factor.

Table 1: Relation between shortage rate and safety factor

Shotage rate	Safety factor
0.1%	3.10
1.0%	2.33
2.0%	2.06
5.0%	1.65
10.0%	1.29

We define safety stock of empty containers with safety factor. Figure 4 shows the concept of safety stock. P_{dp} means the prediction of accumulated demand of empty containers at port p during d days (determine at section 3.2). K_{dp} means the safety stock at port p after d days. And the graph means the probability of demand at port p after d days. If we define K_{dp} as safety stock, the shortage rate is β%. As a result, the definition of safety stock is given by Eq. (1).

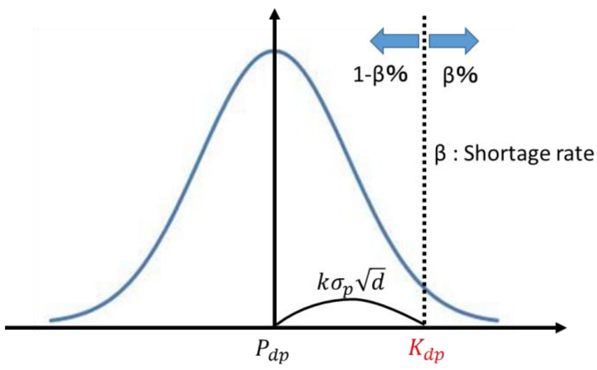

Figure 4: The concept of safety stock

$$K_{dp} = P_{dp} + k * \sigma_p * \sqrt{d} \tag{1}$$

K_{dp} : safety stock
P_{dp} : prediction of accumulated demand
σ_p : standard deviation of demand
d : period of prediction
k : safety factor

3.4 Determine transportation plan

We determine the transportation plan so that the cost of empty container repositioning is minimized. We define the total cost of empty container repositioning as the sum of the storage cost, the lease cost, the handle cost, and the fuel cost. The storage cost is the cost to store the empty containers at port. The lease cost is the cost to lease the empty containers when there is surplus of empty containers at port. The handle cost is the cost to load and unload containers at port. The fuel cost is the cost to transport the containers from a port to another port. We assume that the storage cost, the lease cost, and the handle cost is proportional to the number of containers, and the fuel cost is proportional to the number of containers and the number of voyage days. Therefore, Eq. (2) gives the definition of the total cost. We consider minimizing the total cost.

$$C_{total} = C_{storage} + C_{lease} + C_{handle} + C_{fuel} \tag{2}$$

C_{total} : total cost
$C_{storage}$: storage cost
C_{lease} : lease cost
C_{handle} : handle cost
C_{fuel} : fuel cost

Next, we define the variable of this optimization. We define x_{dsp} as the number of handled empty containers between ship s and port p on day d, and define positive direction of x_{dsp} as the direction from ship to port. We also define y_{dp} as the number of leased containers at port p on day d.

Then, we define the constraints of this optimization. We considered three constraints. First constraint is that the stock of empty containers is more than the stock of safety stock. Safety stock is determined by the inventory control method, which is explained at section 3.3. Eq. (3) shows the first constraint. Second constraint is that the number of containers on the ship is less than the capacity of the ship. Eq. (4) shows the second constraint. Third constraint is that the number of loaded and unloaded containers at port is less than the max quantity of work on the port. Eq. (5) shows the third constraint.

$$PS_p + \sum_d \sum_s x_{dsp} + \sum_d y_{dp} \geq K_{dp} \tag{3}$$

$$0 \leq SS_s - \sum_d \sum_p x_{dsp} \leq MC_s \tag{4}$$

$$z_p \leq MH_p \tag{5}$$

x_{dsp} : number of handled empty containers
y_{dp} : number of leased containers
z_p : number of loaded and unloaded containers
PS_p : previous stock of containers at port
K_{dp} : safety stock of empty containers
SS_s : previous stock of containers on ship
MC_s : capacity of ship
MH_p : max quantity of work

3.5 Simulation

We carry out marine logistics simulation to optimize empty container repositioning. This simulation includes demand prediction, inventory control, and determine transportation plan. Figure 5 shows the procedures of marine logistics simulator.

The input of this simulation is origin-destination data, port data, and ship data. Origin-destination data is the data of container trade data. We predict the demand data of empty containers from this origin-destination data. Port data includes the container storage fee, the container lease fee, the container handle fee, and the max quantity of work. Ship data includes the fuel fee, the capacity, and the round schedule of ship.

Through this simulation, we acquired the output. The output is the cost of logistics, the stock of containers at each port, and the quantity of work at each port.

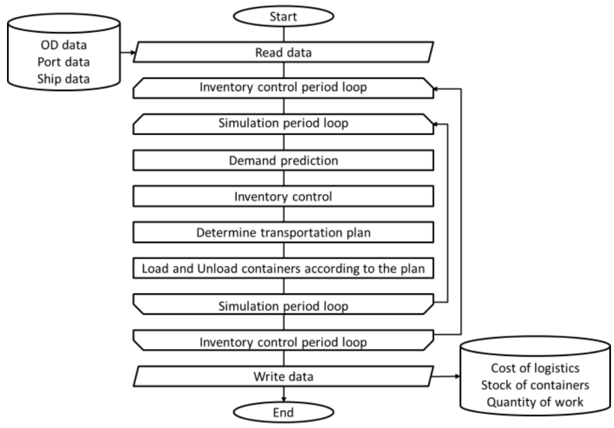

Figure 5: Procedures of marine logistics simulator

4. CASE STUDY

4.1 Scenarios of simulation

We apply this model to the marine logistics network. Figure 6 shows the network of this case study. This network consists of seven ports and six links.

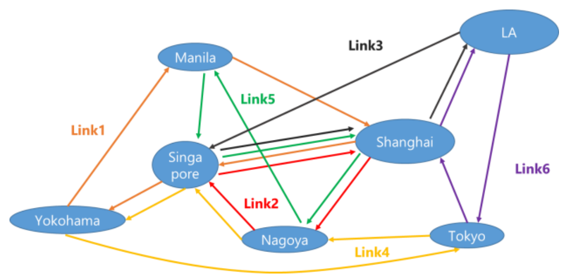

Figure 6: Network of this case study

Table 2 shows the schedule of ships on each link. Judging from Table 2, it takes 14 days to ship around the Link 1, and it takes 21 days to ship around the other links. Most of the liner shipping is weekly service in practical. To reproduce weekly service, two ships are required on Link 1, and three ships are required on the other links. Therefore, we consider 17 ships in this case study.

Table 2: Schedule of ships on each link

date	day	Link ID 1	2	3	4	5	6
1	Mon	Singapore					LA
2	Tue		Singapore		Shanghai		
3	Wed						
4	Thu				Nagoya	Tokyo	
5	Fri	Manila		Yokohama			
6	Sat			Tokyo			
7	Sun			Nagoya			
8	Mon	Yokohama					
9	Tue					Shanghai	
10	Wed		Shanghai				
11	Thu	Shanghai			Manila		Singapore
12	Fri						
13	Sat						
14	Sun		Nagoya	Singapore	Singapore		
15	Mon	Singapore					
16	Tue						
17	Wed					LA	Shanghai
18	Thu						
19	Fri						
20	Sat						
21	Sun						
22	Mon						LA
23	Tue		Singapore		Shanghai		
24	Wed						
25	Thu					Tokyo	
26	Fri			Yokohama			
27	Sat						
28	Sun						

Table 3 shows the origin-destination matrix of full containers in this network. According to this matrix, there is short of empty containers at Shanghai, and there is surplus of empty containers at Los Angeles.

Table 3: Origin-destination matrix of full containers

(TEU/year)	Singapore	Tokyo	Yokohama	Nagoya	Manila	Shanghai	LA
Singapore	0	6,300	4,200	3,500	3,600	9,450	6,400
Tokyo	4,300	0	0	0	0	12,900	40,000
Yokohama	2,800	0	0	0	4,500	8,400	0
Nagoya	2,400	0	0	0	3,700	7,200	0
Manila	1,200	0	4,100	3,400	0	800	0
Shanghai	16,000	33,000	21,000	18,000	9,800	0	144,000
LA	3,200	20,000	0	0	0	72,000	0

Then, we assumed three scenarios. When the number of ordered empty containers is defined, we consider demand prediction, inventory control, and optimized transportation plan in scenario 1. (This is our proposal model.) On the other hand, we only consider the number of empty containers which is used on the day before in scenario 2. Figure 7 shows the concept of determination of ordered empty containers in scenario 2.

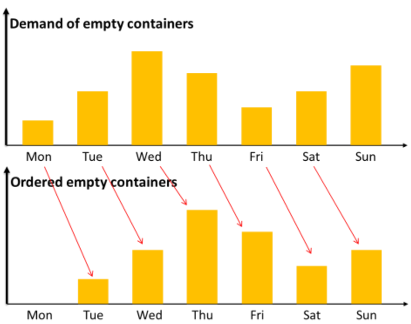

Figure 7: Concept of determination in scenario 2

Moreover, we change the storage cost and the handle cost per one container in scenario 3. Table 4 shows the storage cost and the handle cost per one container in scenario 1 and scenario 2. Table 5 shows the storage cost and the handle cost per one container in scenario 3.

Table 4: Cost per one container in scenario 1 and scenario 2

(yen/container)	storage cost	handle cost
Singapore	400	7,000
Tokyo	1,500	30,000
Yokohama	1,500	30,000
Nagoya	1,500	30,000
Manila	1,500	30,000
Shanghai	800	30,000
LA	1,200	30,000

Table 5: Cost per one container in scenario 3

(yen/container)	storage cost	handle cost
Singapore	400	7,000
Tokyo	1,500	30,000
Yokohama	1,500	30,000
Nagoya	1,500	30,000
Manila	1,500	30,000
Shanghai	400	7,000
LA	1,200	30,000

We carry out marine transport simulation under these assumptions. Simulation period is one years. We verification the three hypotheses through this simulation: The cost of empty container repositioning is reduced in scenario 1 compared with scenario 2. The empty containers are repositioned from Los Angeles to Shanghai in scenario 1 and scenario 3. The storage of containers in Shanghai is increased and storage of containers in Singapore is decreased in scenario 3 compared with scenario 1.

4.2 Simulation results

After the marine transport simulation, we evaluate the simulation result. Figure 8 shows the cost of empty container repositioning in scenario 1 and scenario 2. According to Figure 8, 129 trillion yen is reduced in scenario 2 compared with scenario 1.

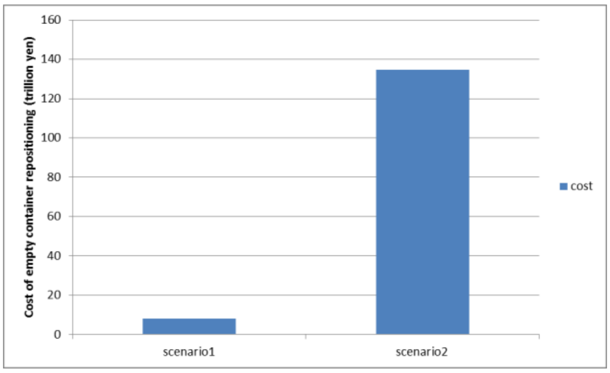

Figure 8: Cost of empty container repositioning

Figure 9 shows the stock of empty containers at each port in scenario 1, and Figure 10 shows the stock of empty containers at each port in scenario 2. According to Figure 9, the stock of empty containers is convergent at each port. This result suggests that empty containers are repositioned from Los Angeles to Shanghai in scenario 1. On the other hand, according to Figure 10, the stock of empty containers is divergent at Los Angeles. This result suggests that empty containers are not repositioned from Los Angeles to Shanghai in scenario 2.

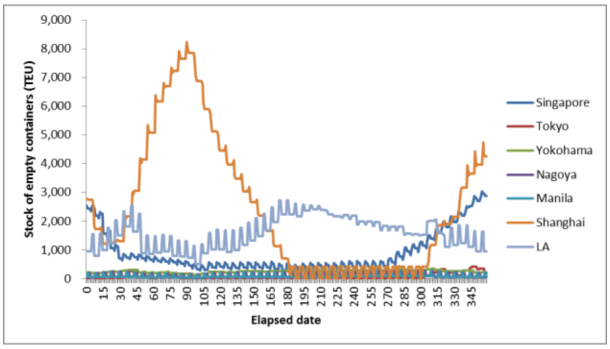

Figure 9: Stock of empty containers in scenario 1

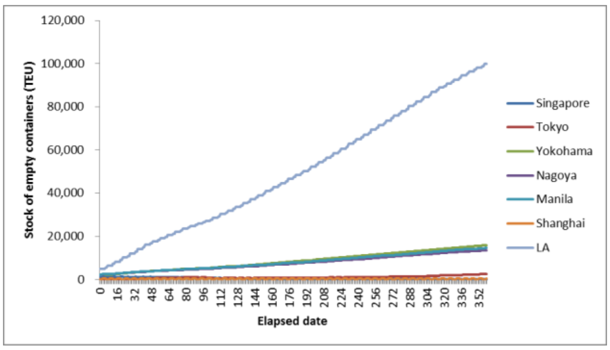

Figure 10: Stock of empty containers in scenario 2

Figure 11 shows the stock of empty containers at each port in scenario 1. According to Figure 9 and Figure 11, the storage of containers in Shanghai is increased and storage of containers in Singapore is decreased in scenario 3 compared with scenario 1. This is because the storage cost and the handle cost in Shanghai in scenario 3 is lower than scenario 1. This result suggests that the amount of the storage of containers in the port depends on the storage cost and the handle cost of containers of that port.

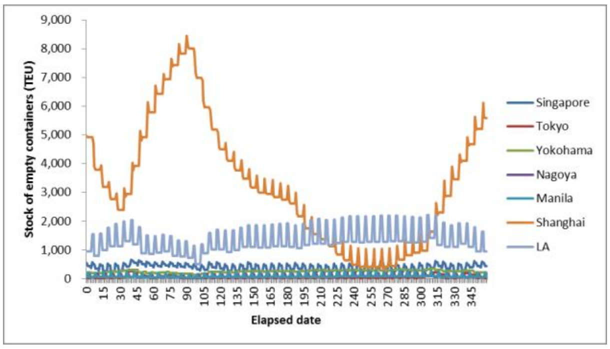

Figure 11: Stock of empty containers in scenario 3

Through this case study, we confirm that the cost of empty container repositioning is reduced and the empty containers are repositioned in our proposal system. Moreover, we confirm that the amount of the storage of containers is changed when the storage cost and handle cost is changed.

5. CONCLUSION

We designed a planning system to reduce the cost of repositioning empty containers. This system includes demand prediction, inventory control, and planning marine transportation.

We applied this model to the marine logistics network, and evaluate the result of this simulation. We achieved to reduce cost and reposition empty containers.

In future research, we can make the model to search the best storage cost and the best handle cost of containers for the port owner to maximize profit of port.

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